Paleontological Analyses of North Pacific Ocean-Bottom Cores[1]

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ABSTRACT: Three North Pacific ocean-bottom cores were studied. Core No. 1 was taken on the rim of the Aleutian Trench, south of Attu Island; core No. 2, about 140 miles south of Attu Island; and core No. 8, on the Marcus-Necker Ridge. The upper 40 cm of core No. 1 is almost entirely organic material and the remainder of the 315-cm core is predominantly glacial marine sediments. Climatic conditions and source of clastics are inferred. Core No. 2 was of virtually no stratigraphic value, due to the reworking of the sediments. The upper 200 cm of core No. 8 were analyzed, dated, and correlated with other low-latitude cores, with core No. 1, and with cores from the central Arctic Ocean studied by Soviet scientists. A foraminiferan generally believed to be Tertiary was found in association with Pleistocene foraminiferan species.

The analyses confirm the basic premise of the Ewing and Donn theory of ice ages, and suggest that stadial intervals are mainly ones of slow glacial wastage.

UNDER AN INFORMAL PROPOSAL submitted by the author and three colleagues[3] and approved by ESSA, eight ocean-bottom cores were taken by USC&GS "Pioneer" (ESSA Cruise PIO 457, April 1965) on a traverse between Attu Island and Johnston Island. The author's analysis is a micropaleontological one, designed to contribute information on the thermal regimen of the North Pacific Ocean in the upper Quaternary. This entails, fundamentally, a study of the incidence of steno-thermal pelagic skeletal remains as a function of chronology.

Figure 1 shows core locations and Table 1 gives pertinent data. The cores were taken with a 20-foot Kullenberg piston corer. They are stored in the ESSA oceanographic laboratory, Seattle, Washington. Part of the material was extracted and brought to the Hawaii Institute of Geophysics for analysis.

METHOD OF STUDY

For purposes of micropaleontological analysis, the cores were sampled at every 5 cm from top to 100 cm, and below that at every 10 cm. The method of Thomas (1959) was used to determine the incidence of foraminifera and ostracods. These were charted as a function of depth and number per square centimeter. The technique of W. E. Riedel (personal communication) was used in the study of Radiolaria. In this method, material is examined on a Canada balsam mount. The results of our work to date follow.

ANALYSIS OF THE CORES

Core No. 1. North Rim of the Aleutian Trench

The following are dominant sediments in this core:

Top to 25 cm:	diatomaceous ooze (more than 96%)
25 to 40 cm:	*Globigerina* ooze, *G. pachyderma* (more than 45%)
40 to 315 cm:	glacial marine sediments (except for the 65-cm layer, which was 90% radiolarian)

The term "glacial marine" was used by Philippi (1912) to describe deposits of ice-rafted terrigeneous sediments ranging from silt (0.002 to 0.02 mm in diameter) to gravel (2.0 cm in diameter and greater). In this core, glacial marine sediments are poorly sorted, suggesting a lack of turbidity currents or a weakness of bottom currents.

Radiolarians were present in all layers ex-

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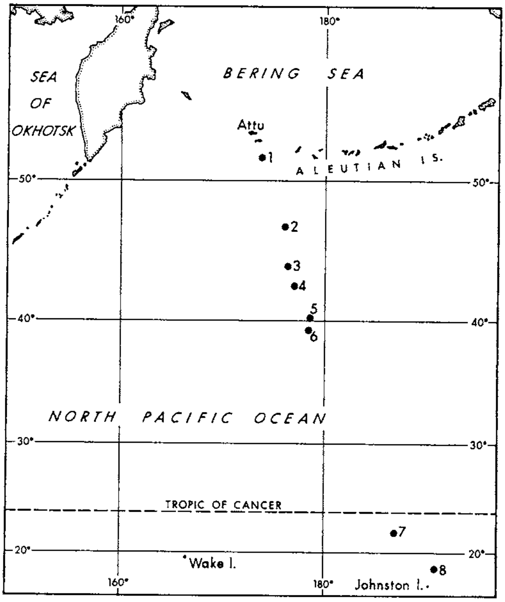

FIG. 1. Coring positions, ESSA Cruise PIO 457 (1965).

amined. In all, 79 genera and 63 species have been identified. Cold-water, cosmopolitan, and warm-water forms were present from top to 25 cm. Below the 25-cm layer, all species were cold-water forms—with one possible exception. At 65, 75, 100, and 230 cm, a species identified as *Cenosphaera favosa*, and known from warm surface-water, occurred. However, according to Hays (1965), it may be synonymous with *C. nagati*, a cold-water Antarctic (probably bipolar) species. The synonymy seems valid because, wherever *C. favosa* appears, it is associated with cold-water fauna.

Forty-six species of foraminifera were found in the core. Between 25 and 40 cm, the species *Globigerina pachyderma* was dominant.[4] It also was present in most layers of the core and in association with cold-water and cosmopolitan species of Radiolaria. Of the benthonic foraminifera, *Nonion labradoricum* and *Uvigerina canariensis* occurred in most layers. A lone specimen of the warm-water planktonic *Globorotalia tumida* was found at 20 cm. Its occurrence appears to have been exotic.

Diatoms dominated the top 25 cm of the core, and were present in all layers except at 230 and 240 cm. Because their sinking rate in the abyssal province is known to be low (Lohman, 1942), they were not used here individually as stratigraphic criteria.

Glacial marine clastics in this core are, in the main, products of volcanism, consisting largely of basalts, rhyolites, olivine, amygdaloids, and obsidian. Quartz was abundant. The quartz pebbles were mostly well weathered.

The source of this glacial marine material can be hypothesized as follows: According to Péwé et al. (1965), the southern Alaskan ice sheet during the Wisconsin glacial stage was nourished by winds sweeping over the North Pacific Ocean in a north to northeasterly direction. This, under the influence of Coriolis force and the continental shelf, would set up a permanent easterly current along the Aleutian chain and the south coast of Alaska.

[4] When examined, some of the smaller forms resembled *G. bulloides* and may well have been the same. But Ericson et al. (1964) believe that this form is an immature stage of *G. pachyderma*.

TABLE 1

CORES OBTAINED BY USC & GS "PIONEER" ON ESSA CRUISE PIO 457 (1965)

CORE NO.	LATITUDE	LONGITUDE	CORE LENGTH	DEPTH (fms)	REMARKS
1	51°45′N	173°40′E	10′6″	1750	Aleutian Trench
2	46°20′N	176°00′E	14′8″	3050	Broad E-2 bathymetric trend
3	44°40′N	176°45′E	Phleger	3090	Broad E-2 bathymetric trend
4	43°00′N	177°20′E	9′4″	3080	Broad E-2 bathymetric trend
5	40°10′N	178°30′E	15′10.5″	3015	Mendocino extension
6	39°40′N	178°30′E	17′5″	3060	Mendocino extension
7	22°15′N	172°45′W	18′5″	2750	Basin between Marcus-Necker Ridge and Hawaiian Swell
8	19°40′N	170°50′W	14′7″	1670	Marcus-Necker Ridge

Ewing and Donn (1961) show a map of Pleistocene glaciation in the northern hemisphere. They believe the principal source of glacial nourishment was an ice-free Arctic Ocean. The map shows a northern Siberian ice sheet with separate but glaciated areas in Kamchatka and in Koryakskiy. The latter glaciated area overruns the continental shelf. Holmes (1965) says ". . . there is no doubt that a land bridge of tundra type but not glaciated was well over 1,000 miles wide (through Bering Strait) for long intervals of the Pleistocene." On this premise the northern Siberian ice sheet would be ruled out as a source of Pacific sedimentation since icebergs must be calved into the sea, and here the southward flowing Oyashio current would have swept any Kamchatkan icebergs well south of the Aleutian Trench. However, icebergs calved from Koryakskiyan glaciers would have been carried eastward into the permanent easterly current (as hypothesized above) and thus could have transported the glacial marine material. Since the glacial marine deposits are uninterrupted between 45 and 315 cm, it would appear that sedimentation by ice-rafting must have been quite rapid because approximately 40,000 years, conservatively, are represented by 275 cm of sediment. Correlation of this and other Arctic cores is shown in Figure 2.

Since no glacial marine material is present above the 40-cm layer, it would appear that terrestrial ice was in general retreat during the time represented in this interval. Such a retreat must have been caused by a frozen Arctic Ocean with consequent wastage (see Ewing and Donn, 1956), or by a rise in mean annual temperature, or both.

Core No. 2. Approximately 140 Miles South of Attu Island

Mere mention will be made of this core because it is of no apparent stratigraphic value, due to re-working of the sediments. Radiolaria and diatoms dominated all layers. Clastics were poorly sorted. Miocene radiolarians appeared in the top layers and Recent species at depth, and vice versa. Minute bits of what appeared to be glass were present at 65 to 70 cm and at 350 to 365 cm, giving the sediments a crystalline appearance. These fagments were clear and optically isotropic, and are believed to be volcanic shards (Harold Stearns, geological consultant, conversation). No calcareous material was present. (The shards appeared in dominant quantity at the 175-cm layer in both core 4 and core 5. Neither of these cores nor cores 3 and 6 have yet been analyzed.)

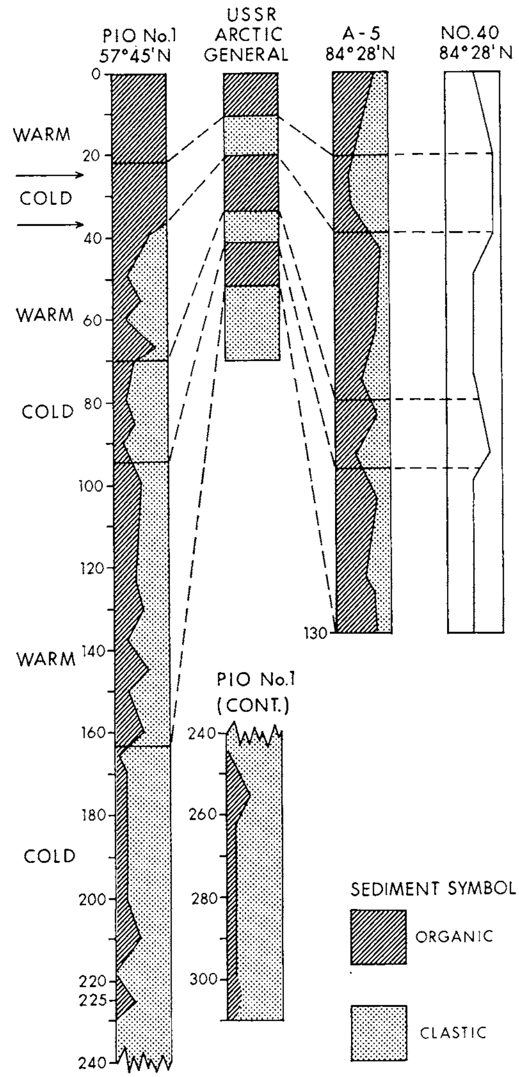

FIG. 2. Correlation of core No. 1 with USSR generalized Arctic core (after Saks et al., 1955); with A-5 (after Thomas, 1965) and with No. 40 (after Ericson et al., 1964*a*); A-5 and 40 are the same core. Thermal regime of A-5 based on assemblages of foraminifera tests and ostracod carapaces. Thermal curve of core No. 40 based on abundance of *Globigerina pachyderma*. (Core depths in centimeters.)

TABLE 2

PELAGIC FORAMINIFERA

FAMILY/SPECIES	DEPTH (cm)															
	Top	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
	Number of Specimens per Square Centimeter															
GLOBIGERINIDAE																
Globigerina bulloides (d'Orbigny)	1	15	10		8	2		8	3	5	4	0.2			4	
G. eggeri Reuss	3	14	1	25	2		4	1	1		8	8	4	14	1	5
Globigerinoides conglobata (Brady)	31	15	30	31	40	25	6	12	10	30	14	15	25	26	6	17
G. triloba (Reuss)	2	19	20	5	20	4	2	10	15	4	1	5	4	4	2	5
G. rubra (d'Orbigny)	50	31	12	42	8	4	40	12	8	20	22	28	10	10	9	7
G. sacculifera (Brady)	4	4		6		10	2	3	1	2	5	5	1	14	1	2
G. sacculifera var. *fistulosa* (Schubert)								0.2			0.1	0.2				
Hastigerina aequilateralis (Brady)	2	2	2	2		1	10	4	2	2	1	2	8	1	1	8
Orbulina universa d'Orbigny	10	20	25	12	2	15	2	16	4	5	1	4	0.7	8	6	2
Sphaeroidinella dehiscens (Parker and Jones)	4	3	10	4	1	8	6	16	4	25	20	8	10	11	10	12
Candeina nitida d'Orbigny					7	4	1	2		2	1	1	0.5	0.2	1	
GLOBOROTALIDAE																
Globorotalia menardii tumida (Brady)	27	21	40	35	16	10	24	20	30	23	20	21	33	36	20	17
G. truncatulinoides (d'Orbigny) right coil	6	5	6	2	15	1	2	2	2	2	8	9	8	10	2	3
G. truncatulinoides (d'Orbigny) left coil	8	5	13	8	8	2	8	8	4	10	9	3	3	1	6	3

TABLE 2 (*continued*)

FAMILY/SPECIES	DEPTH (cm) 80	85	90	95	100	110	120	130	145	150	160	170	175	185	190	200
	Number of Specimens per Square Centimeter															
GLOBIGERINIDAE																
Globigerina bulloides (d'Orbigny)	1					1					2			0.1	8	4
G. eggeri Reuss	4	3	4	4	0.2		1	1	1			0.7	0.2	1	1	1
Globigerinoides conglobata (Brady)	5	10	17	25	9	4	10	10	5	10	1	2	10	15	10	10
G. triloba (Reuss)	4	1	2				0.5			10	1	3	2	10	1	2
G. rubra (d'Orbigny)	5	2	5	2	6	5	1	10	10			2	1	20	2	
G. sacculifera (Brady)	6				1		0.5						0.5		1	
G. sacculifera var. *fistulosa* (Schubert)					4			2	1							
Hastigerina aequilateralis (Brady)			4	2					1	2	1		1			
Orbulina universa d'Orbigny	2	3	8	10	19	10	35	50	20	21	20	30	8	19	25	30
Sphaeroidinella dehiscens (Parker and Jones)	50	40	65	60	28	40	20	50	40	80	88	92	91	100	53	48
Candeina nitida d'Orbigny						1									1	1
GLOBOROTALIDAE																
Globorotalia menardii tumida (Brady)	20	24	35	40	20	22	25	50	30	80	41	60	80	35	50	32
G. truncatulinoides (d'Orbigny) right coil	8	10	8	8	4	8	9	2	0.5	4	8	1	2	3	2	
G. truncatulinoides (d'Orbigny) left coil	3	1	2	2	2	4	1	0.5	2		3	3		2	5	

Core No. 8. Marcus-Necker Ridge

The upper 200 cm of this core, the southernmost in the profile, was analyzed to provide Wisconsin and Recent criteria. From top to bottom, the core is more than 99.5 percent calcareous foraminifera shells, with only a few grains of manganese oxide, quartz, and metamorphic materials, and a few specimens of arenaceous foraminifera. Of the calcareous foraminifera, the pelagic species were by far the more abundant, in some instances exceeding 100 per square centimeter (see Table 2). By contrast, no benthonic foraminifera exceeded 10 per square centimeter; most species were sparsely scattered throughout the layers. In all, 179 pelagic or benthonic species were identified (Table 2 lists only the pelagic species). The 25-cm layer was dated by carbon-14 and found to be $35 \times 10^3 \pm 300$ years B.P. Extrapolation (see Ericson et al., 1964*b*) shows the 200-cm layer to have been deposited ca. $280 \times 10^3 \pm 300$ years B.P.

Several authors have investigated thermal tolerances and preferences of pelagic foraminifera. Their findings (Table 3) were used to prepare the curve (Fig. 3, curve *4*) reflecting the thermal regimen of surface waters over core No. 8 as a function of time. Corroborating criteria were provided by the direction of coiling of *Globorotalia truncatulinoides* (see Ericson et al., 1954).

For purposes of comparison, two other curves are shown in Figure 3. A current mean annual surface-water temperature of 26°C was used as the criterion by which to compare probable past temperatures at about the mid-Pacific, ca. latitude 20°N (Klaus Wyrtki, personal communication).

An inspection of the curves (Fig. 3) as well as a generalized curve by Ericson et al. (1964*b*)

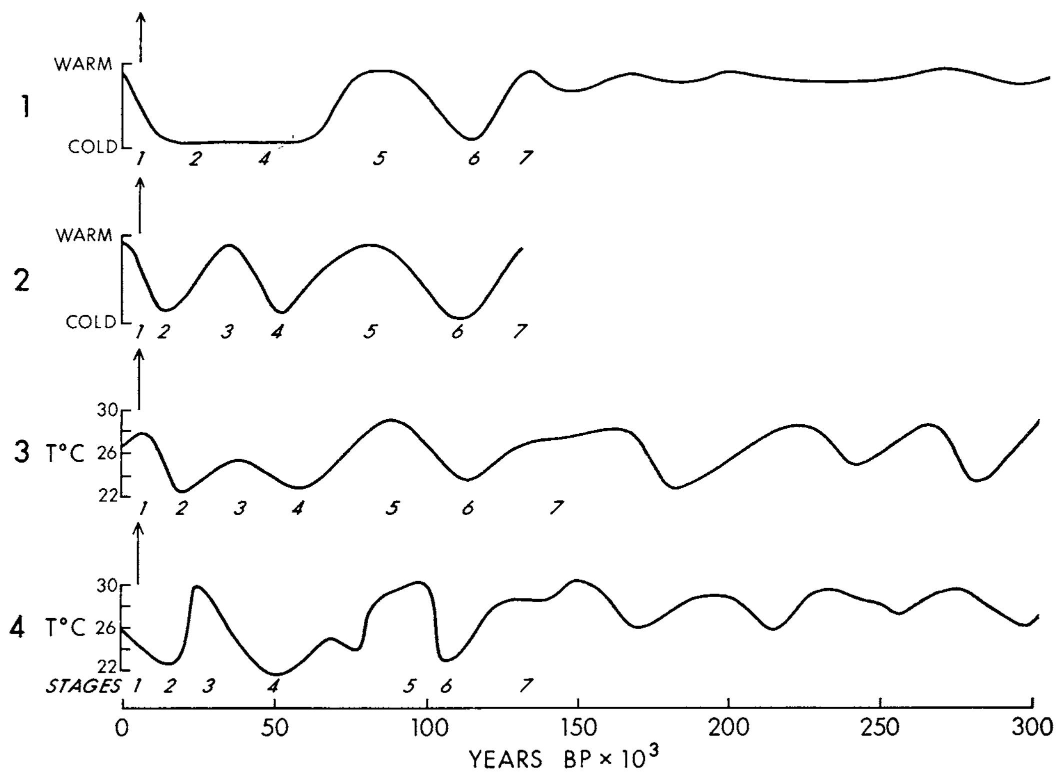

FIG. 3. Postulation of post-Illinoian relative sea-water temperatures: *1*, Atlantic (after Ericson et al., 1964); *2*, Andaman Sea (after Frerichs, 1968); *3*, central Caribbean (adapted from Emiliani, 1966); and *4*, mid-Pacific, based upon thermal preference of pelagic foraminifera. See text for explanation of stages.

TABLE 3

THERMAL PREFERENCES OF CERTAIN PELAGIC FORAMINIFERA
(Temperatures in degrees centigrade)

FORAMINIFER	BANDY* RANGE	BANDY* MOST ABUNDANT	BÉ AND HAMLIN* RANGE	BÉ AND HAMLIN* MOST ABUNDANT	KANE*
P. obliquiloculata	18–30°	25–30°	ca. 18°		Over 20°
G. bulloides	0–30°		12–40°		Cosmopolitan
G. pachyderma	Less 15°		4.4–18°	11–13°	
G. eggeri	8–32°				
G. conglobata	15–30°		21–27°	25–27°	Over 20°
G. rubra	10–30°		18–27°	23–27°	Cosmopolitan
G. sacculifera			21–26°		Warm
G. triloba	17–30°				
H. aequilateralis	10–27°		15–27°	20–23°	Cosmopolitan
O. universa	10–30°	12–17°	12–26°	20–26°	Warm
S. dehiscens	23–30°	25–28°	Cosmopolitan		Equatorial
Candeina nitida			Never under 18°		Over 20°
G. menardii	17–30°	20–25°	Tropical		Over 20°
G. tumida	17–31°	27–30°			Over 20°
G. truncatulinoides	13–27°	22–27°	Over 18°		Warm
G. scitula	8–12°		Deep water		Cosmopolitan

TABLE 3 (*Continued*)

FORAMINIFER	BRADSHAW* RANGE	BRADSHAW* MOST ABUNDANT	ASANO*	PARKER* RANGE	PARKER* MOST ABUNDANT
P. obliquiloculata	18–31°	26°	Warm		24–27°
G. bulloides	11–23°	12°	Cosmopolitan	Relatively cold	
G. pachyderma	9–20°	12°		Polar to tropical	S of 35°S
G. eggeri	9–32°	19°	Warm		16–27°
G. conglobata	Warm	20°	Warm		18–27°
G. rubra	Over 19°	28°	Warm		10–27°
G. sacculifera	17–32°	26°	Warm		18–28°
G. triloba					
H. aequilateralis	16–32°	29°	Warm		10–24°
O. universa	10–20°	13–17°	Warm (when abundant)		
S. dehiscens	Over 23°			S. Pacific	N of 50°
Candeina nitida	14–30°	17°			
G. menardii	17–27°	29°	Warm (when abundant)		18–27°
G. tumida	19–30°	28°	Warm		
G. truncatulinoides	17–27°		Warm (when abundant)		
G. scitula					9–12°

* Bandy (1964); Bé and Hamlin (1967); Kane (1956); Bradshaw (1959); Asano (1957); Parker (1960).

for the Atlantic Ocean (not shown here) indicates a good correlation between temperatures in the four areas considered. However, there are some incongruities. For example, curves *2* and *4* in Figure 3 clearly show seven post-Illinoian stages: (1) Recent, (2) Late Wisconsin Stadial, (3) Late Wisconsin Interstadial, (4) Mid-Wisconsin Stadial, (5) Early Wisconsin Interstadial, (6) Early Wisconsin Stadial, and (7) Sangamon Interglacial. Though Emiliani's (1966) curve (Fig. 3, curve *3*) shows chronologically similar events, he identifies stage 3 as the sole Wisconsin Interstadial and assigns stage 5 to the Sangamon. The same is shown by the curves of Ericson et al. (1964*b*) who also identify only one Wisconsin Interstadial.

Emiliani (1966), using $0^{18}/0^{16}$ ratios of pelagic foraminiferal tests to determine paleotemperatures, postulated a "climatic optimum" ca. 7,000 years B.P. During this interval temperatures are presumed to have been ameliorated to a greater degree than are today's. Such an interval is not reflected in the complete analysis of core No. 8, nor does it appear to be indicated in Frerichs' (1968) analysis (Fig. 3, curve *2*). However, Figure 4, based solely on the direction of coiling of *Globorotalia truncatulinoides* indicates warmer conditions 7,600 years B.P. than prevail today. Ewing and Donn (1961) refer to it as a "minor climatic fluctuation." However, in the main, it supports Thomas' (1966) conclusion that temperatures vary regionally with fluctuation of ocean currents.

An interesting finding in the analysis of the core was the presence of *Globigerinoides sacculifera fistulosa* in abundance at 100 cm. It was present in association with *Globorotalia truncatulinoides* and 100-percent sinistrally coiled *Globorotalia menardii tumida*. No discoasters

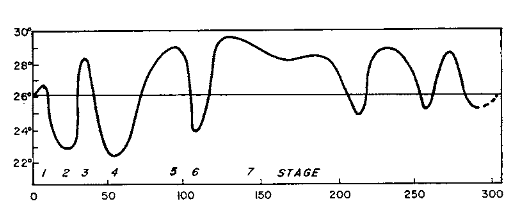

FIG. 4. Paleo-thermal properties at 19°40'N, 170° 50'W, based solely on right- or left-coiling of *Globorotalia truncatulinoides* (see Table 2).

were present. Hence the sediments are unquestionably Quaternary. Such an assumption has the concurrence of Ruth Todd (affiliate communication). This form is believed by Ericson et al. (1963) and Riedel et al. (1963) to have been extinct at the beginning of the Pleistocene.

CONCLUSIONS

As indicated in Figure 2, the transition, in core No. 1, from diatomaceous to *Globigerina* ooze at about 25 cm coincides with the disappearance of warm-water species of Radiolaria beneath that layer. This probably marks the Pleistocene-Recent boundary. Moreover, the transition below 40 cm from organic to glacial marine deposits seems equally significant. Correlating these events with the climatic regimen proposed by Saks et al. (1955)[5] and assuming the validity of the Ewing and Donn (1961) theory of ice ages, the following interpretation is suggested: The last glacial retreat began with the freezing of the Arctic Ocean ca. 19,000 years B.P., represented by the 40-cm layer, prior to which time glaciers enjoyed a good state of health. According to Holmes (1965) thousands of years of wastage were required before sea level was raised sufficiently to permit the flow of warm Atlantic water into the Arctic Ocean (as evidenced by core No. 1). In the case of the Late Wisconsin Stadial interval, nearly 10,000 years elapsed between the peak of terrestrial ice and the break-up of Arctic sea ice. Organic changes in the sediments around 25-cm depth evidently mark this break-up with consequent re-establishment of Pacific-Arctic water exchange.

SUMMARY

1. The Late Wisconsin Interstadial interval was one during which ice sheets formed and built up to a maximum ca. 19,000 years B.P., that is, the inception of the Late Wisconsin Stadial. The latter interval was one of cold conditions during which ice sheets wasted slowly

[5] This regimen is summarized as follows:

YEARS B.P.	CLIMATE	INTERVAL/EPOCH
0–9,500	Warm	Recent
9,500–19,000	Cold	Late Wisconsin Stadial
19,000–30,000	Warm	Late Wisconsin Interstadial

away from lack of nourishment. The same may be said of previous stadial and interstadial intervals.

2. The use of *Globigerinoides sacculifera fistulosa* as a Tertiary criterion is not necessarily valid.

3. Generalizations from the curves shown in Figure 3 suggest the following thermal regimen for tropical waters:

YEARS B.P.	CLIMATE
0–9,000	Warm
9,000–22,000	Cold
22,000–40,000	Warm
40,000–60,000	Cold
60,000–105,000	Warm
105,000–120,000	Cold
120,000–305,000	Warm

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